Bandwidth in Electro-Magnetic Compatibility (EMC) Testing

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ABSTRACT

Electro explosive devices (EEDs) are often required to undergo a test in which they are placed near a high-power radio transmitter. The purpose is to see whether electromagnetic energy might fire the EED.

Consideration of the "Q" or quality factor of an EED system affords guidance in choosing a transmitter and test procedure. This can lead to shorter, simpler tests, and to improved efficiency in electromagnetic-exposure tests of all kinds.

Keywords: bandwidth, EED, electro explosive device, electro-magnetic compatibility test, EMC test, HERO test, irradiation test, quality factor

Any system that contains an electrically fired explosive device may be required to undergo electro-magnetic compatibility (EMC) testing. In practice, the system is placed near the antenna of a radio transmitter. The transmitter output is increased to a high level. Thus, the system is "bathed" in electromagnetic radiation, usually very intense. Any possible ill effects are noted. In particular, for an electroexplosive device (EED), the purpose of this test is to see whether such exposure to an intense electromagnetic field might cause the explosive to fire. This kind of EMC test, where the device under test is explosive, is called a HERO test. HERO is an acronym for "Hazard of Electromagnetic Radiation to Ordnance". Ordnance, of course, is anything explosive.

Figure 1 illustrates the type of EMC test to be discussed. A radio-transmitting antenna is at the upper left. At the lower right is a system containing an EED. The system might be a weapon, an automobile with airbags, or anything else. The whole system has not been drawn, only the EED part of it.

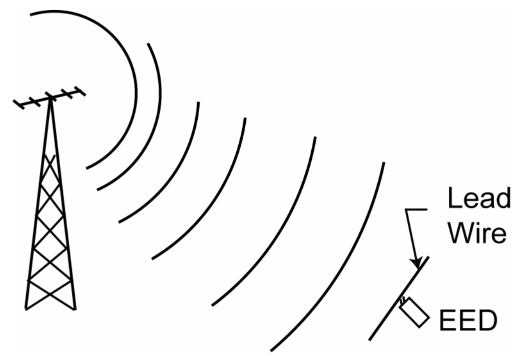

Figure 1. Setup for an EMC test that irradiates an EED.

An electroexplosive device, or EED, is a little can containing explosive material with a fine metal bridgewire inside. The bridgewire leads to longer wires that connect the EED to its firing circuit. When electric current passes through the bridgewire, it gets very hot and causes the charge to explode. In Figure 1, the leadwires are stretched out to form a radio-receiving antenna. The purpose of the EMC test is to determine whether the electromagnetic radiation might produce enough current in the bridgewire to fire the EED.

Test engineers generally conduct this kind of EMC test over a "band" or range of frequencies. The idea is to include all frequencies where, in real life, one might encounter a significant amount of electromagnetic energy. This should include the range of frequencies at which radio transmitters might be operating at the site or sites where the EED system will be located.

The antenna that is used for the test needs to be set to emit radiation that has the same strength at any frequency.

Initially, often nothing is known about the response of the EED system to radio frequency (RF) energy. Initially, the simplest case possible is considered where it is assumed that the same amount of RF power dissipates in the EED at any frequency.

Figure 2 depicts such a case. The power dissipated in the EED is along the vertical axis. The irradiation frequency is along the horizontal axis. This picture shows the response of this imaginary EED system. It is a flat line. For this type of EED system, irradiation at any frequency is as effective as irradiation at any other frequency, so it is not necessary to test the system at more that one frequency to determine whether the field is a hazard to the EED. This is an idealized, extreme case. Usually, the amount of RF power dissipated in the EED will depend upon frequency. In other words, there will be some kind of resonance in the EED system.

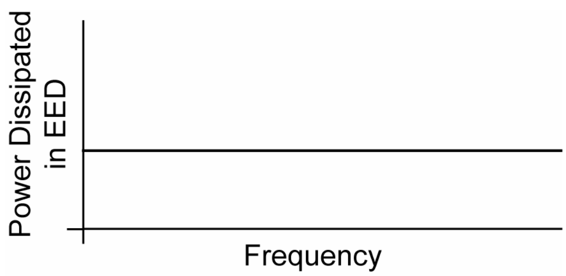

Figure 2. Frequency-independent EED system.

In Figure 3 the power dissipated in the EED is along the vertical axis, and it seems to peak at one particular frequency. This is called resonance. At one particular frequency f_0, the resonance frequency, more power dissipates in the EED than at other frequencies for the same incident field strength. Again, it is assumed that an electromagnetic field, whose strength does not change with frequency, irradiates the EED system. This resonance affects the EED itself, and the system of which it is a part, but it does not affect the transmitter. The peak of the resonance is at frequency f_0. That is where the power absorbed in the EED has its maximum value. The arrows to the left and right of the peak indicate the place on the curve where the power absorbed is half the maximum. The width between the arrows Δf is called the full-width at half-maximum (FWHM) power. This is the bandwidth of the EED system.

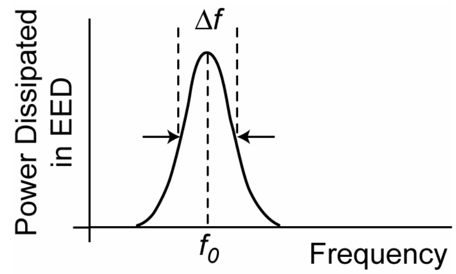

Figure 3. Resonance in EED system.

Clearly, when the transmitter is operated in an EMC test, the EED system needs to be irradiated at or near its characteristic resonance frequency, that is, near the peak of the curve. This is to try to determine the possible bad effects of electromagnetic radiation. In fact, this is trying to see whether the EED will fire. Thus, the system should be irradiated at the frequency where the system absorbs the most energy, to reveal any bad effects.

However, neither the resonance frequency of our EED system nor the width of the resonance is known in advance. Since only the frequency of the transmitter can be controlled, looking for the resonance in the EED system can be like looking for a needle in a haystack.

This is how test engineers perform an EMC test. A radio-transmitting antenna irradiates an EED system as in Figure 1. The radio transmitter can operate on only one frequency at a time. Therefore, the transmitter covers the whole range of frequencies, or bands, in a stepwise fashion. The technicians first set the transmitter to the lowest frequency, then to the next higher frequency, and so on. The difference between successive test frequencies is the frequency interval, or step size. One must specify the step size, in advance, as part of the test plan. At each frequency, the transmitter is turned on for a certain amount of time, perhaps several seconds, before moving to the next frequency. The time when the transmitter is on, at a single frequency, is the dwell time.

Both the frequency step size and the dwell time will affect the total duration of the EMC test. To make this clear, some values will be selected; for example, assume that the transmitter is on for 10 seconds at each test frequency; in other words, the dwell time is 10 seconds. Assume that an EED system is being irradiated over the frequency band from 5 to 11 MHz. The step size is 0.1 MHz (100 kHz). One first turns on the transmitter at a frequency of 5.0 MHz for 10 seconds, then 5.1 MHz for 10 seconds, then 5.2 MHz for 10 seconds, and so on. The total number of steps will be 60. Since each step takes 10 seconds, the total duration of this test will be 600 seconds or 10 minutes. If engineers desire to cover a larger frequency band, then the total test duration will be longer. If technicians need to change or adjust the transmitting equipment to provide RF power at certain frequencies, then the time required for the test will increase. To cover a very large band of frequencies, sometimes engineers must irradiate an item for a whole day or even for several days. For practical reasons, such a long test time can be inconvenient, or even impossible.

In these circumstances, one should remember that the total time for the EMC test also depends upon the size of the frequency-step chosen. To shorten the test, a test engineer can pick a larger step size. How can the appropriate step size be determined?

In Figure 4 the frequency step size is very small. The test frequencies are shown as vertical bars. There are a great many of them. The spacing between these test frequencies is δf. During an irradiation test, the transmitter steps from one frequency to the next. It can take from a few minutes to many hours for the transmitter to step through the whole sequence of test frequencies.

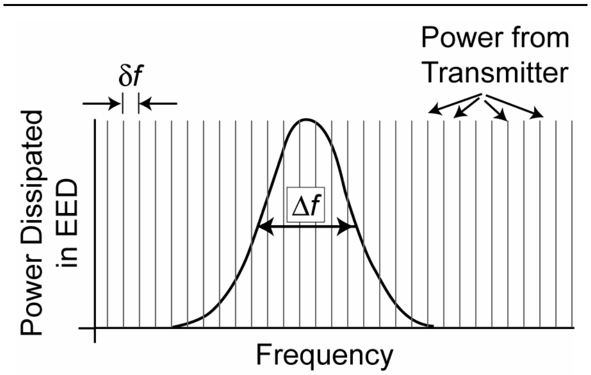

Figure 4. Too many frequencies.

If the EED system under test has a resonance, shown as the curved line in Figure 3, then the width of this resonance is Δf. The technicians performing the EMC test do not know where the EED system resonance is located, nor do they know the width of the resonance. In Figure 4, δf is much smaller than Δf. The reason for stepping the irradiating transmitter through such closely spaced frequencies is ensure that some of the test frequencies fall inside the resonance curve. However, with this particular choice of test-frequency spacing, there is needless duplication of data. The interval between test frequencies, δf, is too small in relation to the bandwidth of the EED system resonance, Δf. Stepping the transmitter through all these frequencies wastes time.

Figure 5 illustrates the opposite problem. The step size, between adjacent test frequencies, is too large. As the test engineer steps the transmitter from one frequency to the next, it completely misses the EED resonance. The entire extent of the EED resonance is between two test frequencies. Note that the spacing between test frequencies is quite large compared to the width of the EED system resonance. This is not good. The step size needs to be smaller than the inherent bandwidth of the EED system under test. In other words, as the transmitter is stepped through the sequence of test frequencies, it is important the peak of the EED system's response is not missed.

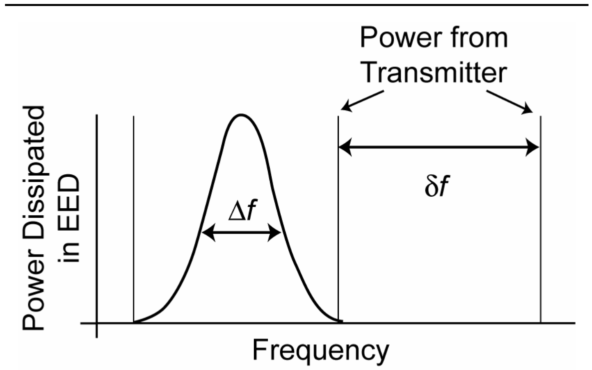

Figure 5. Too few frequencies.

Figure 6 shows the best choice of test-frequency interval. Note that several test frequencies fall within the envelope of the EED system sensitivity. There are enough test frequencies to determine the response of the EED system at the very peak of sensitivity. However, the test frequencies are far enough apart to avoid needless duplication of data.

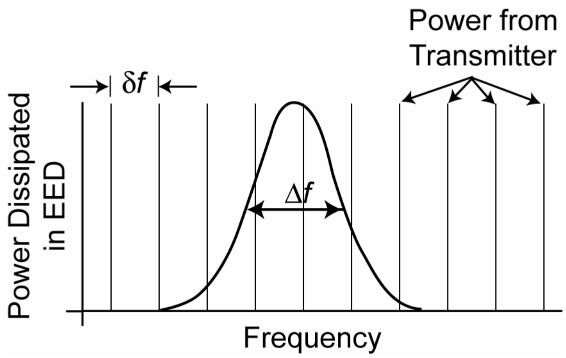

Figure 6. Ideally spaced frequencies.

The spacing between the test frequencies is δf. The width of the EED resonance is Δf. The optimum choice is to have δf smaller, but not too much smaller, than Δf. This relationship can be quantified by saying that the test-frequency interval δf should be approximately half of Δf. In general, the EED bandwidth Δf is not known. However, a reasonable estimate can be made that will choose the best step size for δf.

Remember that the electroexplosive device (EED) is part of a system. A radio transmitter beams RF energy toward this system. The strength of the transmitter's electromagnetic field needs to be at least as large as that which the EED system is likely to encounter while it is in use. Since the transmitter can be set to discrete frequencies in the chosen band, the frequency band is chosen to coincide with the frequencies in the environment where the EED system will be used. The purpose of the EMC test is to determine whether this radiation might adversely affect the EED and the system of which it is a part. It is certainly important to know if the electromagnetic field, to which the system will be exposed during use, could possibly cause the EED to fire unexpectedly. The safety of personnel and equipment depend on this knowledge.

The EED's response to the electromagnetic field has a resonance; that is, it absorbs more power in a certain range of frequencies than it does at other frequencies. It is assumed that the EED and the wires attached to it form a resonant circuit like the one shown in Figure 7. The curves in the line at the top represent a coil, that is, an inductive component. The zigzag line at the top represents a resistor. This is the resistance of the EED bridgewire. The parallel lines at the bottom represent the circuit capacitance. The EED circuit under test may not have components that look exactly like the ones illustrated in Figure 7. However, if there is a resonance in the EED system, then this is an adequate representation. The ensemble in Figure 7 has a resonance frequency, and it can store energy. The wires in Figure 7 that stretch to the left and right form an antenna. This antenna can pick up radio frequency energy from any nearby transmitter.

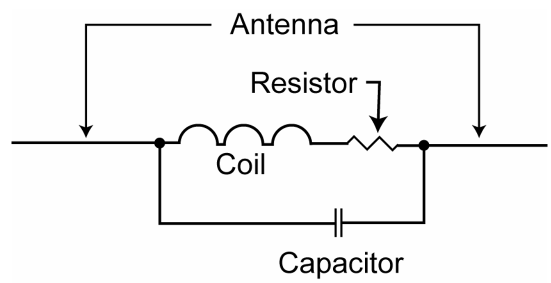

Figure 7. Model of resonant EED system.

Radio engineers have been building resonant circuits like that in Figure 7 for a long time. At low frequencies, the best ones are made with silver-plated wire. At high frequencies, silver-plated cavities are used. The characteristics and the attainable limits of this type of resonant circuit are well known.

When discussing the width of the resonance, it is useful to bring in the concept of Q, the quality factor. The quality factor Q is defined as the ratio of the resonance frequency f_0 to the resonance bandwidth Δf of the EED-system, as shown in equation 1. Both the frequency and the bandwidth must be in the same units (e.g., if f_0 is given in megahertz, then Δf must also be in megahertz; if f_0 is given in kilohertz, then Δf must also be in kilohertz).

$$Q = \frac{f_0}{\Delta f} \tag{1}$$

The quality factor is not merely a mathematical abstraction. Radio engineers have found that for any circuit composed of wires, resistors, and capacitors, like that in Figure 7, Q will be less than 100. This practical limit is expressed in equation 2

$$Q < 100 \tag{2}$$

Therefore, if our EED system has a resonance, the Q of this resonance will be less than 100. This means that the bandwidth of the resonance in our EED system, if there is a resonance, will be greater than one percent of the resonant frequency, as expressed in equation 3.

$$\Delta f > \frac{f_0}{100} \tag{3}$$

Recall our discussion regarding the spacing between the test frequencies, δf. If this quantity is too small, the test procedure will waste time and resources. However, if δf is too large, the test may not reveal important details of the EED response such as a resonance. The optimum choice is to have δf smaller, but not too much smaller, than Δf, the width of the EED system power absorption curve. Ideally stated the test-frequency interval δf should be approximately half of Δf.

$$\delta f \approx \frac{1}{2}\Delta f \tag{4}$$

Because of the practical limit on Q, it is known that the EED system bandwidth is greater than one percent of the operating frequency as shown in equation 1. As a general rule, the best choice for the test-frequency interval is greater than, or equal to, one two-hundredth of the operating frequency as shown in equation 4.

$$\delta f \geq \frac{f_0}{200} \tag{5}$$

Remember that the limit on the quality factor is independent of the precise location of the resonance frequency or of its width. It applies to any resonance, wide or narrow. Therefore, the lower limit on the step size δf is also independent of the details of the resonance. It is not necessary to know anything in advance about the resonance. When an engineer is preparing a test plan for an EMC test on an EED system, the engineer needs to specify a test-frequency interval δf greater than, or equal to, one two-hundredth of the operating frequency f_0. This will guarantee the discovery of any resonances of the system in the frequency range being considered, yet it will avoid unnecessary duplication of data. Equation 6 shows how to calculate the best test-frequency interval for any operating frequency.

$$\delta f \geq \frac{f}{200} \tag{6}$$

Table 1 shows sample test frequencies, with recommended intervals (step size).

Table 1. Optimum Step Size for Various Operating Frequencies.

Operating Frequency	Step Size
200 kHz	1 kHz
1 MHz	0.005 MHz
10 MHz	0.0550 MHz
100 MHz	0.5 MHz
800 MHz	4 MHz
2000 MHz	10 MHz